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Development and Evaluation of Mechanical Properties of Rubber Matrix Composite for Automobile Transmission Belt Application

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Abstract: *The importance of automobile transmission belts (ATB) in mechanical systems cannot be overemphasized. In developing countries, conventional ATB are mostly imported. Most of the imported ones lack sufficient strength, which makes them prone to frequent fracture, they are weak and break easily. This could lead to accidents and damage to engines. Also, frequent replacement of these belts increases the cost of maintenance. In this study, Rubber Matrix Composite has been developed using natural rubber reinforced with polyester fiber and carbon black particulates to modify and overcome these challenges. The produced samples were subjected to physical and mechanical tests. It was observed that the composite hardness increased gradually as polyester fiber reinforcement increased. The sample with fiber reinforcement of 8% exhibited a hardness value of 25.6 HV. Also, the sample without carbon black showed higher levels of water absorption of 20.5%, other samples showed lower levels of water absorption. The result of tensile strength revealed that the sample reinforced with only carbon black exhibited a low tensile strength of 30.30MPa, while the sample reinforced with both materials exhibited the highest tensile strength of 52.61MPa. Generally, the composites exhibited an increase in the mechanical properties as the weight percentage (wt.%) of the reinforcement increased. This study established that high-quality ATB can be produced locally using natural rubber and reinforcements.*

Keywords: *Mechanical Properties, Rubber-polyester Composite, Transmission Belt, Carbon Black, Wear Resistance*

1. INTRODUCTION

Automobile Transmission Belt (ATB) is a flexible material used to connect two or more rotating shafts together; they are used to transmit power or movement in a mechanical system. The use of belts in mechanical systems cannot be over emphasized, but the disadvantage associated with using them is that most of these belts are imported and lack sufficient strength [1], which makes them prone to frequent fracture, they are weak and break easily. To improve the belt life, the rolling friction needs to be reduced, and the hardness of the belt needs to be increased [1]. Also, there is a need for an upgrade in the design of ATB materials.

Some researches were carried out on the use of rubber matrix composite for automobile applications. Natalia and Wladyslaw [2], researched on the use of Styrene-butadiene rubber and short fiber less than 1cm long. From the results it was observed that the presence of fibers increased the viscosity of the mixes. The mixture containing fillers had a higher torque value showing higher cross-linking. The optimum cure time slightly decreased with the increase in fiber loading and the change in scorch time was also slight.

Kumar and Rajesh [3], studied on how to develop a rubber composite that are eco-friendly, economical and biodegradable with desired properties like wear resistance, hardness and compressive strength. Banana fiber is the choice of natural fiber used for the experiment. It was observed that the rubber reinforced with untreated banana fiber had a higher abrasion resistance compared to rubber filled with alkali-potassium permanganate treated fiber. The composite offers abrasion resistance due to the rigid and stiff untreated inelastic banana fiber. The fibers property of hardness is incorporated in composites and harder than rubber without fiber reinforcement. It is also seen that untreated fiber reveals maximum compressive strength, the untreated banana fiber.

Egwaikhide et al. [4], investigated on rheological and mechanical properties of natural rubber compounds filled with carbonized palm kernel husk and carbon black. It was observed that carbon black reinforces rubber better than the palm kernel husk. It was also noticed from the experiment that the tensile strength of carbonized palm kernel husk is inferior to that of carbon black due to the particle size of carbon black (0.02 - 0.05 μm), decreasing the particle size of carbon black enhances mechanical properties of rubber.

Bonnia et al. [5], carried out research to investigate the morphological and mechanical properties of rubber toughened polyester kenaf composite when it is exposed to different environmental stress cracking resistance (ESCR) conditions, like distilled water, soil and environmental exposure and artificial sea water. mechanical and morphological properties were then evaluated. It was observed that all samples had a decrease in fracture toughness with increasing time exposure, water absorption at sample surface increases flexibility of composite without harming the inner fiber of reinforcement. Samples exposed to environment had higher hardness compared to other samples in other conditions. Composite exposed to artificial sea water and distilled water had its fiber pulled out due to weakness of the interfacial mechanism between fiber and matrix, the absorption of water in fiber is believed to have prevented the adhesion between fiber surfaces and matrix. The composite exposed to soil fractured together, showing good interfacial bonding between rubber and kenaf fiber.

An attempt has been made by several researchers on how to improve the mechanical and physical properties of polymer composites for automobile applications. However, little or no attention has been given, on how to develop or improve the mechanical properties of Automobile Transmission Belt (ATB). Therefore, the aim of this research is to develop and evaluate the mechanical properties of rubber matrix composites for automobile transmission belt applications.

2. MATERIALS AND METHOD

2.1 Materials

The materials used to carry out these experiments are: Natural rubber, Polyester fiber, Carbon black, Zinc oxide, Stearic oxide, Sulphur, Dioctyl phthalate, and Polyvinyl alcohol. These are shown in Figure 1(a–i).

Figure 1: (a) Natural rubber latex, (b) Coagulated natural rubber, (c) Citric acid powder, (d) Citric acid solution, (e) Stearic acid, (f) Zinc oxide, (g) Carbon black, (h) Sulphur, and (i) Polyester fiber.

2.2 Methods

A commercially available Natural latex rubber was purchased from a registered local vendor in Lagos, Nigeria. Rubber additives such as zinc oxide, stearic acid, Sulphur, Carbon black, Dioctyl phthalate, and polyester fiber were also obtained from a local vendor. The natural rubber latex was first prepared, a coagulating solution was prepared by diluting citric acid in water 10 grams of citric acid was diluted in 90 ml of water and used to coagulate 500 grams of Rubber latex. Citric acid

was used as a coagulant because it can promote the coagulation process by reducing the pH of the rubber latex, which causes the latex particles to aggregate and form a solid mass.

2.2.1 Processing and production of the rubber-fiber composite

The rubber latex was first prepared by coagulating it using a citric acid solution; the coagulum was collected and washed to remove remnant acids. The coagulated natural rubber was left to dry for four days before using it. The mechanical compounding technique was used in this experiment. The solidified rubber was softened using a heating device (Hand Dryer), it was heated until it became soft and pliable with a temperature of 70 °C, cautiously heated to ensure there was no overheating. The rubber was then masticated to make the rubber homogenous and smooth by stretching and folding the rubber continuously.

The carbon black filler was then incorporated into softened rubber, it was mixed by applying pressure through a crude roll mill motion, till the fillers were evenly distributed throughout the rubber. The ASTM D412 test method was used to determine the tensile properties of rubber. Test specimens were cut from a rectangular block measuring 40 × 30 × 3 cm. A universal testing machine (UTM) with a 2000 kN load capacity and a speed range of 1–1000 mm/min was employed, providing precise control over loading rates. The machine's load measurement accuracy is ±1 % of the applied load, ensuring reliable results. A constant crosshead speed of 1 mm/min was maintained throughout all tests. Other additives were added in the order of zinc oxide, stearic acid, sulphur, and dioctyl phthalate, one at a time. It was mixed to ensure thorough dispersion of each additive, applying pressure and using rolling or squeezing motions to promote mixing. Various samples of A, B, C, D and E with different compositions were made using the mix formulation in Table 1.

The compounded rubber was shaped using a cutter and prepared to incorporate the polyester fibers into the rubber compound. Fibers were aligned into vertical and horizontal orientations. After preparation, the sample was cured; it was placed into a suitable pre-heated oven. The curing temperature was set to 175 ^{o}C for duration of 20 minutes. The curing process was monitored to ensure the rubber reached the desired level of vulcanization. After the curing process, the samples were removed from the oven and allowed to cool down to room temperature.

Table 1: Mix formulation of the composite samples

Samples	Fiber (wt.%)	Rubber (wt. %)	Carbon (wt. %)	Zinc Oxide (wt. %)	Stearic Acid (wt. %)	Sulfur (wt. %)	Dioctyl Phthalate (Plasticizer) (wt.%)
A	0	70	8	5	5	6	6
B	2	70	6	5	5	6	6
C	4	70	4	5	5	6	6
D	6	70	2	5	5	6	6
E	8	70	0	5	5	6	6

3. RESULTS AND DISCUSSION

3.1 Hardness of the Composites

The hardness test was carried out in accordance with ASTM [6], using the Vickers scale hardness machine. The results indicate that the hardness of the samples increased with increasing weight of the polyester fiber reinforcement as shown in Figure 2. The composite hardness increased gradually as polyester fiber reinforcement increases with 2 %. The sample with highest percentage of fiber reinforcement of 8% exhibited hardness value of 25.6 HV, higher than sample A with no fiber reinforcement. This indicates that combination of fiber and particulate reinforcement enhances mechanical properties better, through cross-linking. This is in line with research carried out by [2,7].

3.2 Density of the Composites

It was observed that the samples showed a decrease in density as the concentration of carbon black decreased in the samples, as shown in Figure 3. The density decreased from 4.9g/cm^3 in sample A to 3.1g/cm^3 in sample E.

3.3 Water absorption of composites

The water absorption of the samples was measured in line with ASTM [8]. The results obtained are shown in Figure 4. From the results, sample E showed higher levels of water absorption of 20.5%. The other samples A, B, C and D showed lower levels of water absorption. Sample A at 11%, sample B at 13%, sample C at 15%, and sample D at 19.3% respectively. This indicates that there could be pores present in the polymer composites as the percentage of carbon black decreases. These pores increase the permeability of the samples, thereby allowing water to be absorbed. Also, the composites increased in water absorption as the amount of carbon black is reduced, because carbon black is hydrophobic, the lower amounts of carbon black resulted in a less hydrophobic rubber compound, leading to higher water absorption capacity. This is related with observation made by Bonnia et al., and Oreko et al. [5, 9].

3.4 Tensile Strength of the Composites

This was carried out in accordance with ASTM [10]. The results of the stress strain curves of the samples are shown in Figures 5a -5d. It was observed that sample B, C and D increased in tensile strength compared to sample A without fiber reinforcement only Carbon black filler, the unreinforced sample A exhibited tensile strength of 30.30Mpa while Sample D exhibited the highest tensile strength of 52.61Mpa

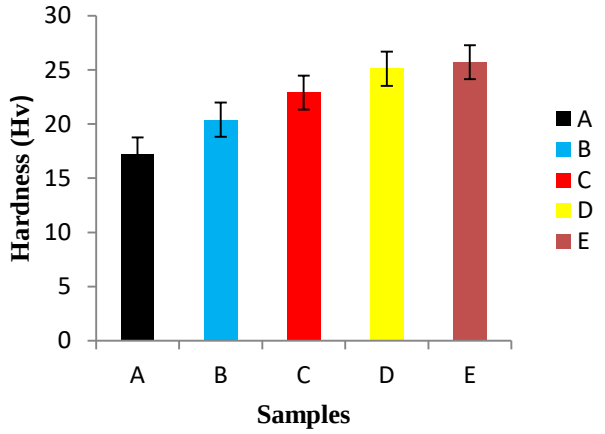

Figure 2: Hardness of the rubber-polyester fiber composites

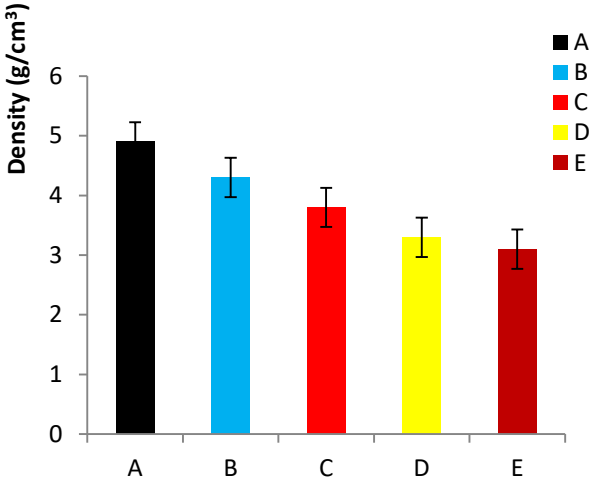

Figure 3: Density of the rubber-polyester fiber composites

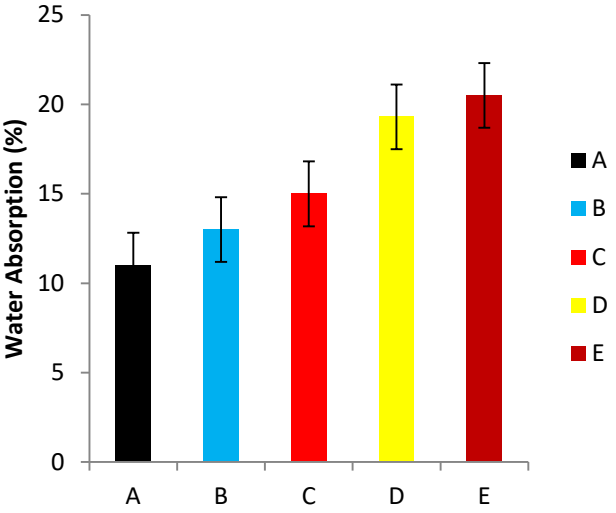

Figure 4: Water absorption of the rubber-polyester fiber composites

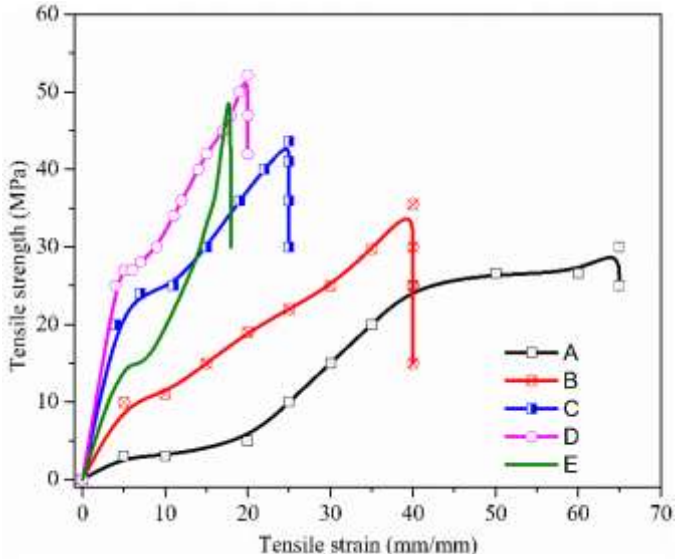

Figure 5: Stress-strain behaviour of rubber-polyester fiber composites A, B, C, D, and E.

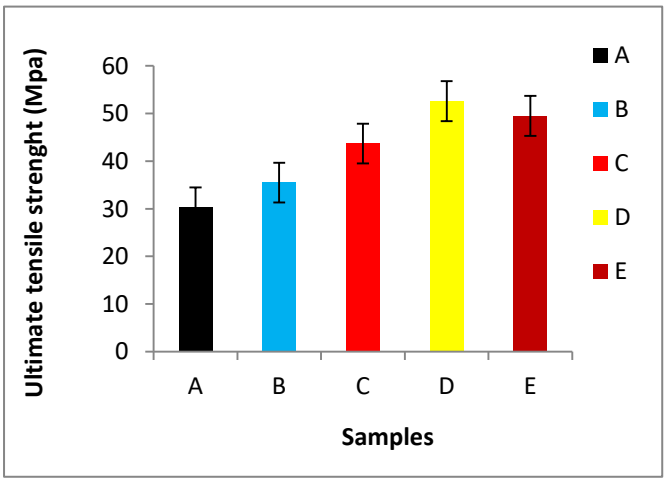

Figure 6: Ultimate tensile strength of rubber-polyester fiber composites A, B, C, D, and E.

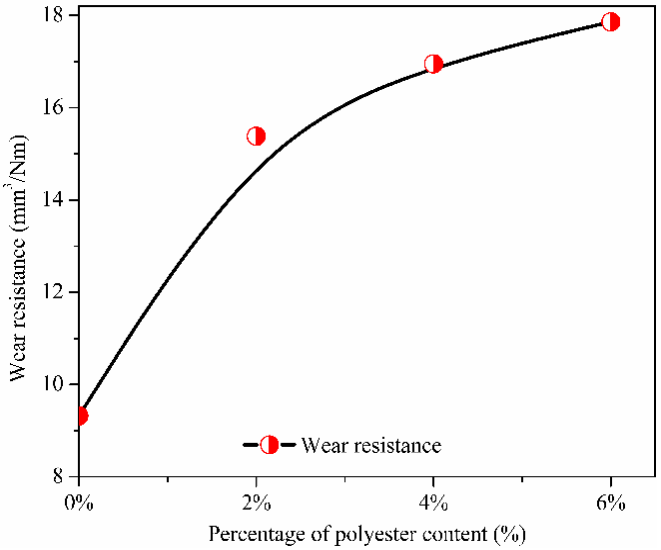

Figure 7: Wear resistance of the rubber-polyester fiber

. However, sample E reduced in tensile strength of 49.52Mpa having higher concentration of fiber but no carbon black filler. This indicates that carbon black also contributes to the tensile strength of the sample, carbon black also improves bonding between rubber molecules. The mechanical properties of the composites also depend on some factors such as the orientation and distribution of the fibers, the rubber matrix phases, the concentration and the stress-strain behavior of the carbon black filler, [4][11]. However, sample B, C and D increased in tensile strength. This can be attributed to the fact that when the samples were subjected to load, the load and stress are transferred from the rubber matrix to the fibers, the fibers acting as carriers leads to uniform stress distribution reducing the stress on the rubber matrix.

3.5 Wear Resistance of the Composite

The wear resistance was carried out in line with ASTM [12]. The result is presented in Figure 7. It was observed that wear resistance increased in samples with increase in polyester fiber concentration, sample A having 0% of fiber had a wear resistance of 9.32, sample B with 2% fiber had wear resistance of 15.38, sample C with 4% fiber had wear resistance of 16.95 and sample D with 6% fiber had 17.86 wear resistance respectively. This follows the same trend with the research by [13]. The presence of polyester fibers helps distribute stress and minimize the wear on the rubber. The fibers act as a protective layer, reducing the contact area and absorbing some of the abrasive forces, thereby increasing the product's resistance to wear [3].

3.6 Microstructure

The micrographs showing the morphology of the composites are shown in Figures 8 – 10. Sample A in Figure 8 revealed a uniformly circular structure, indicating the presence of particulate reinforcement, which leads to a closed-packed structure shown in Figure 8.

In Figures 9 and 10, there are twine-like structures revealing the presence of fiber reinforcement, which contributed to the increase in tensile strength. It looked rougher, which aids mechanical adhesion. Surface area of contact increased, thereby increasing interfacial adhesion [14,15].

The EDS spectra provided evidence of the identified phases such as carbon, as well as some other phases, suggesting the existence of other elements in minute quantities.

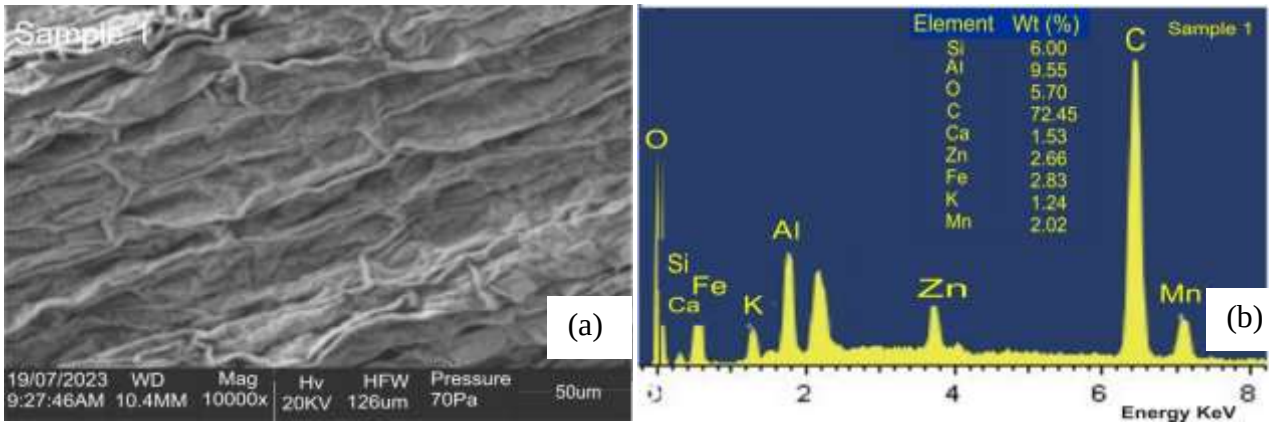

Figure 8: Morphology of rubber-polyester fiber composite A: (a) microstructure, and (b) EDS spectrum.

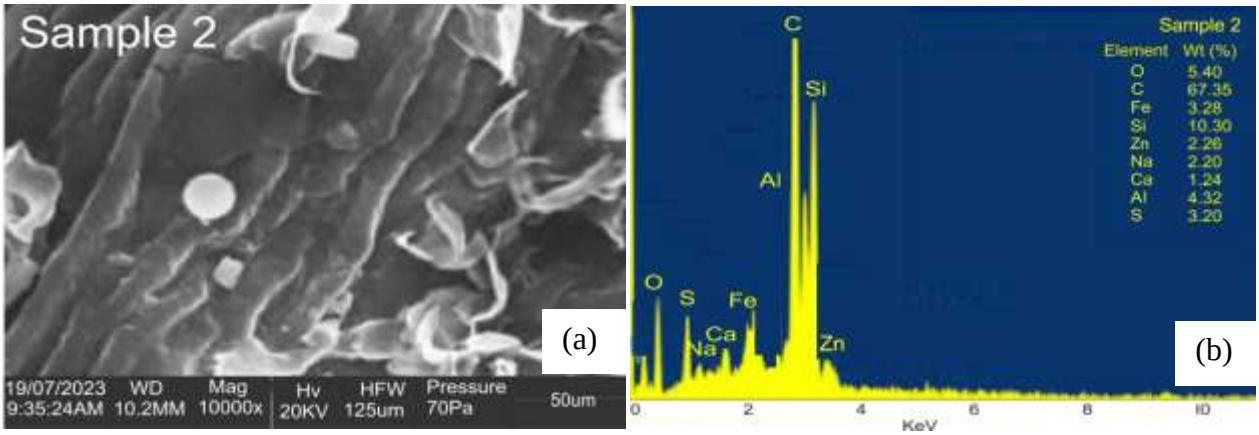

Figure 9: Morphology of rubber-polyester fiber composite B: (a) microstructure, and (b) EDS spectrum.

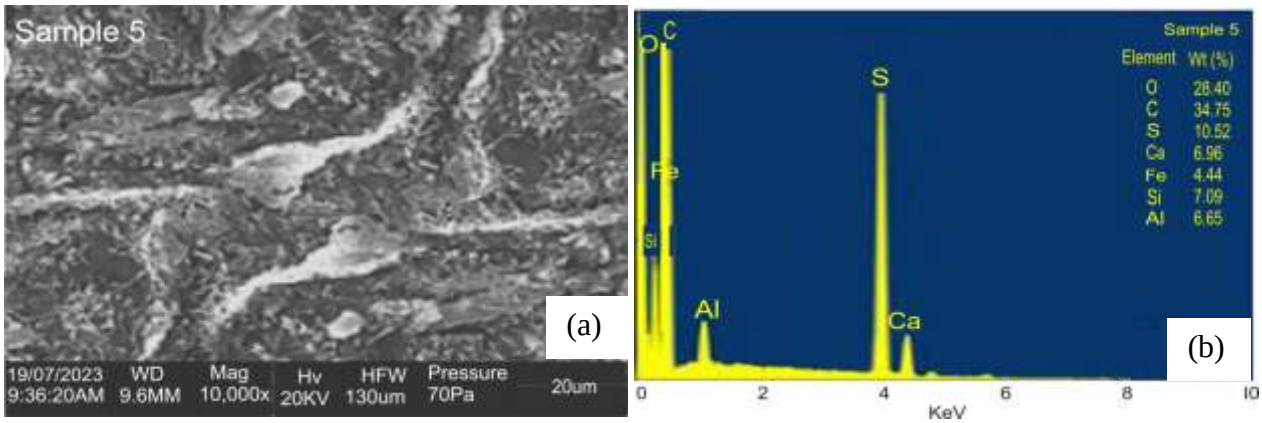

Figure 10: Morphology of rubber-polyester fiber composite E: (a) microstructure, and (b) EDS spectrum.

4. CONCLUSION

In this study, a rubber–polyester fiber composite was developed and subjected to various characterizations. The tensile strength increased in Samples B, C, and D with decreasing carbon black content and increasing polyester fiber content. Despite this variation, the tensile strength remained within the limits recommended by [8]. Additionally, the density of the samples decreased as the carbon black content was reduced, while water absorption increased correspondingly. Except for Sample E, all samples exhibited water absorption levels within the recommended threshold. Polyester fiber, known for its high hardness and stiffness, contributed to an increase in the hardness of the composite samples with increasing fiber content. These hardness values remained within the standard limits specified by [10]. Wear resistance also improved with higher polyester fiber content and remained within acceptable limits.

The properties exhibited by the composite samples indicate that a blend of polyester fiber and carbon black is a suitable reinforcement for rubber-based composites. This has practical implications for local production of ATBs, where incorporating polyester fiber can enhance mechanical performance and durability while utilizing cost-effective and potentially recycled materials. Such developments support localized manufacturing by reducing dependence on imported materials and enabling the production of competitive, performance-grade belts for automotive use.

However, the study has certain limitations. All tests were conducted under dry conditions, which do not replicate the full range of environmental and operational stresses an ATB may face during service. Additionally, the relatively short curing time used in sample preparation may not reflect the optimal or long-term properties achievable with extended curing protocols.

Future studies are recommended to evaluate the fatigue life of the developed composites under cyclic loading conditions typical of ATB operation. Further investigations should include thermal degradation analysis, dynamic mechanical analysis (DMA) to understand viscoelastic behavior, and performance testing under wet or oil-exposed environments to simulate real-world service conditions more accurately. These steps are essential to validate the material's suitability for demanding automotive applications and to optimize formulation for industrial-scale production.

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